Sensitivities of future long baseline experiments in the U.S.

Mark Dierckxsens
University of Chicago

Nufact 07, 6-11 August, 2005
Okayama, Japan

FNAL/BNL study

- ✔ Joint FNAL & BNL study to compare future long baseline experiments in the US
  - ⇨ see talk by M. Bishai for more details
- ✔ This talk about inputs to sensitivity calculations
- ✔ Two detector techniques considered:
  - ✗ Liquid Argon
  - ✗ Water Cherenkov
- ✔ Two neutrino beams considered:
  - ✗ narrow band NuMI off-axis beam to NOvA location
  - ✗ wide band beam to DUSEL site

Long Baseline Experiments

- ✔ Limit to above experiments for this talk
- ✔ More variations have been studied

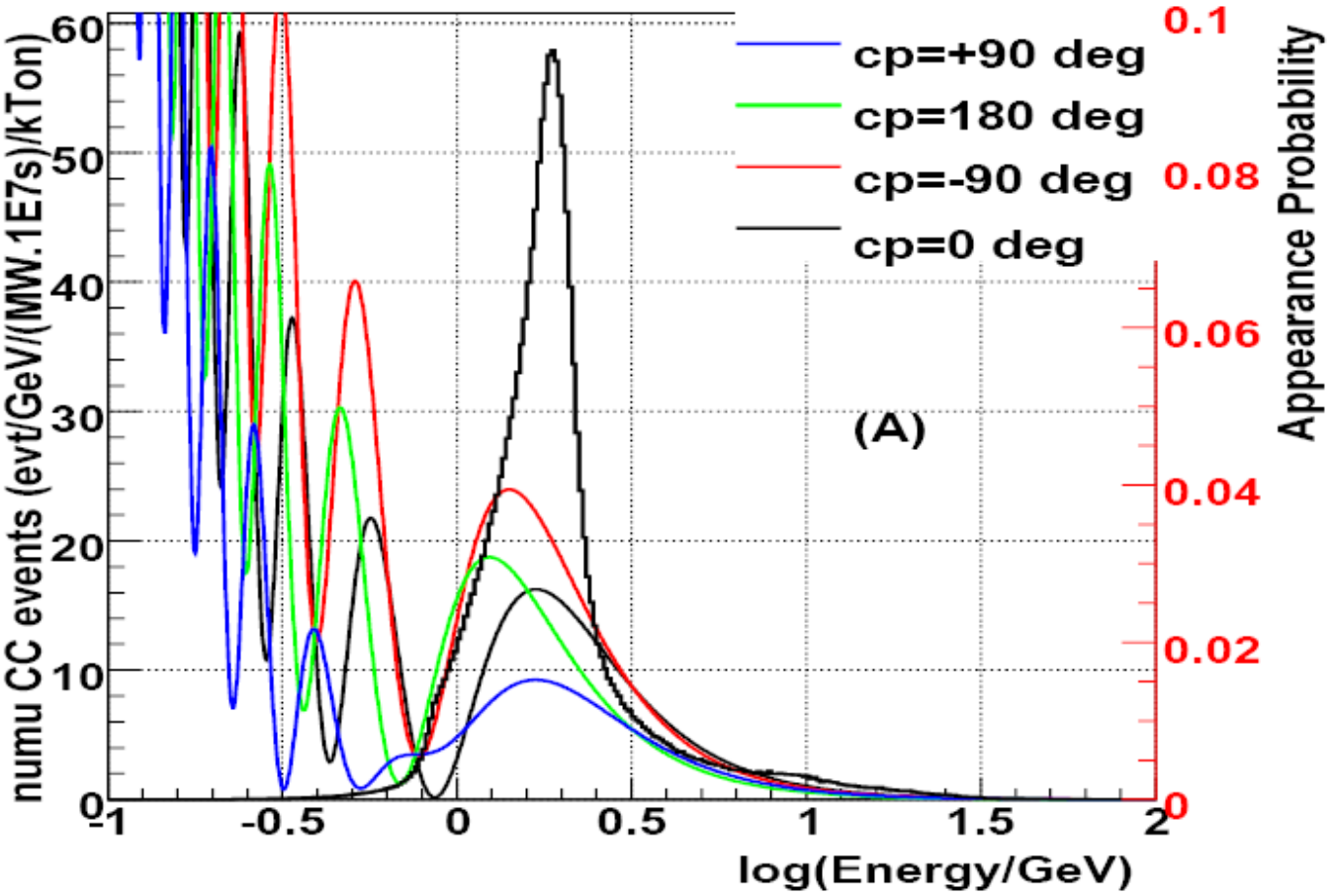
Neutrino Beams

Beam Power

- Possible scenarios for upgrades to increase beam power output of the Main Injector at FNAL:
  ⇨ see talk B. Zwaska
- Calculations for this study mostly done for an exposure of 30 10^{20} protons on target (pot) for neutrino and anti-neutrino running each.
- You can plug in your favorite upgrade and convert this number to length of data taking
- As example:
  1.2 MW 120 GeV proton beam
  @ FNAL: 1.7 10^{7}s/year
  -> 10 10^{20} pot/year

NuMI off-axis

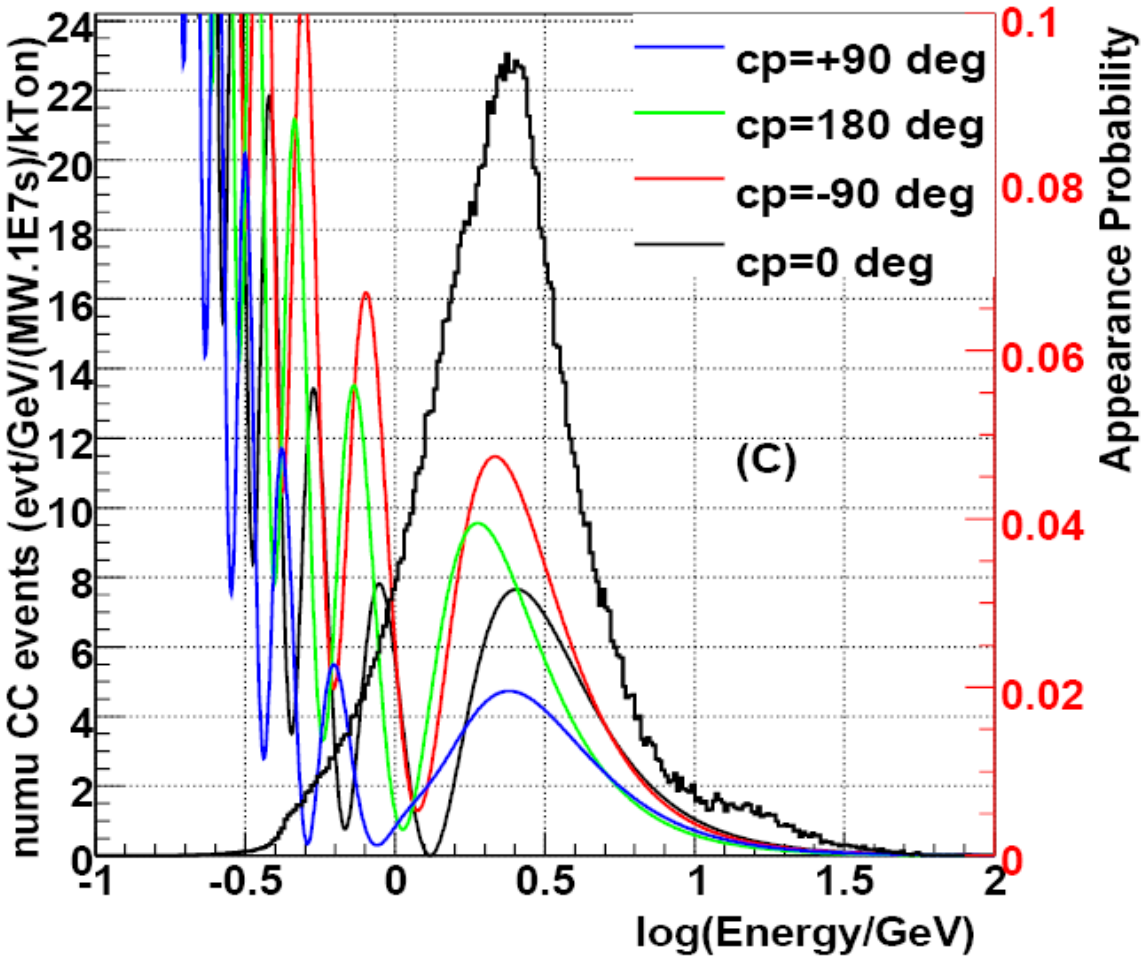
- ν_μ cc event rates and ν_e appearance probabilities for a 0.8° off-axis NuMI beam at 810km



- sensitivities for other options, like placing a detector at 2nd oscillation maximum considered

Wideband beam

- ν_μ cc event rates and ν_e appearance probabilities for a 120 GeV 0.5° off-axis wide band beam at 1300km



- Other proton energies and distances also considered

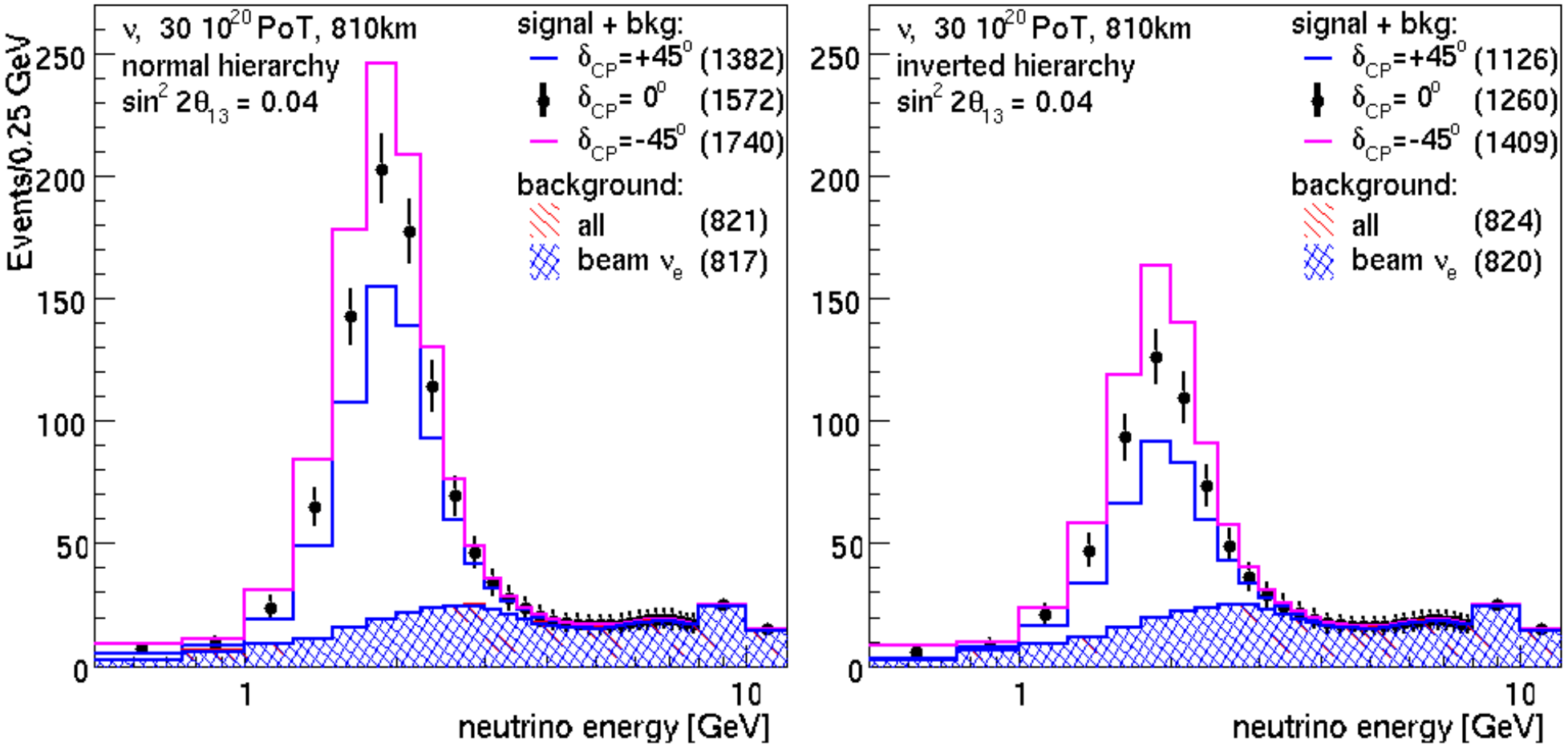
Detectors

Liquid Argon

- 100 kt liquid argon (LAr) detector
- Can be placed at NOvA or DUSEL site
- Signal & background efficiencies based on hand scanning. (B. Flemming et al):
  - ν_e CC efficiency: 80%
  - complete rejection of NC background
- Results confirmed/exceeded using initial automated tools. (A Curioni)
- Energy resolution for
  - QE CC: 5% $\sqrt{E}$
  - non-QE CC: 20% $\sqrt{E}$

LAr spectra @ NOvA

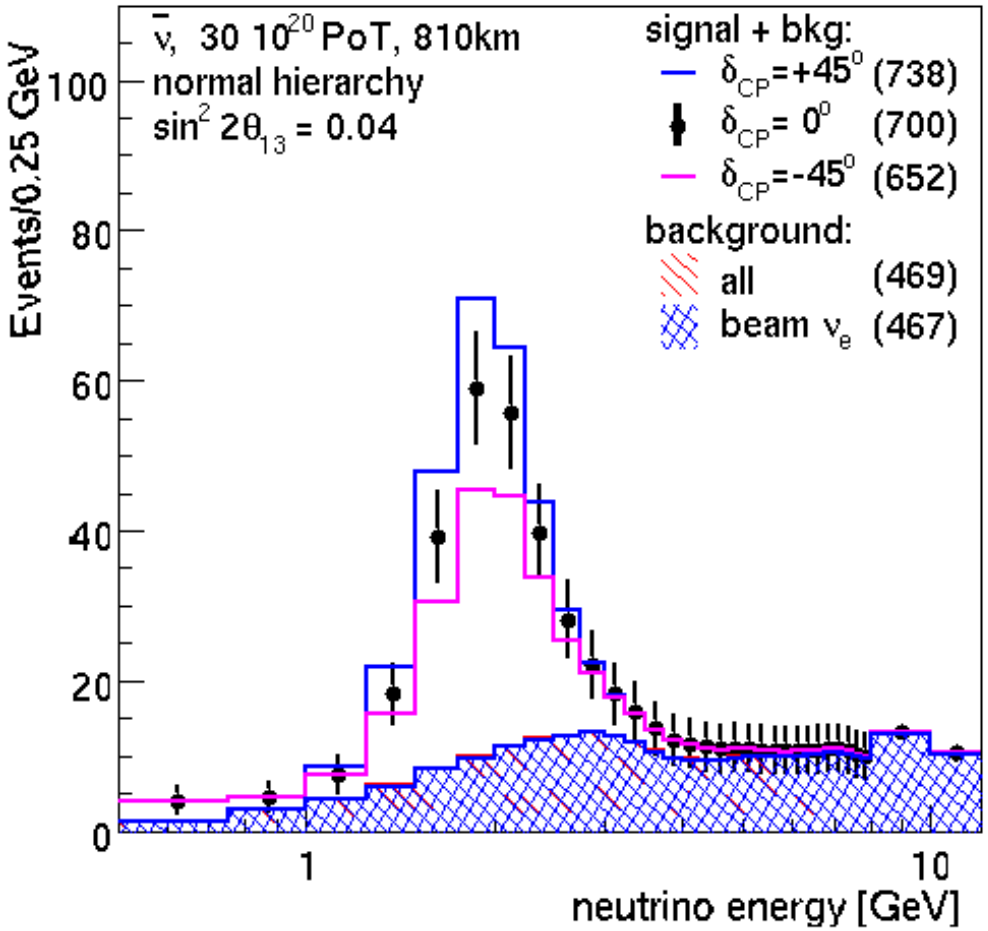
- ✔ Neutrino running and $\sin^2 2\theta_{13}=0.04$

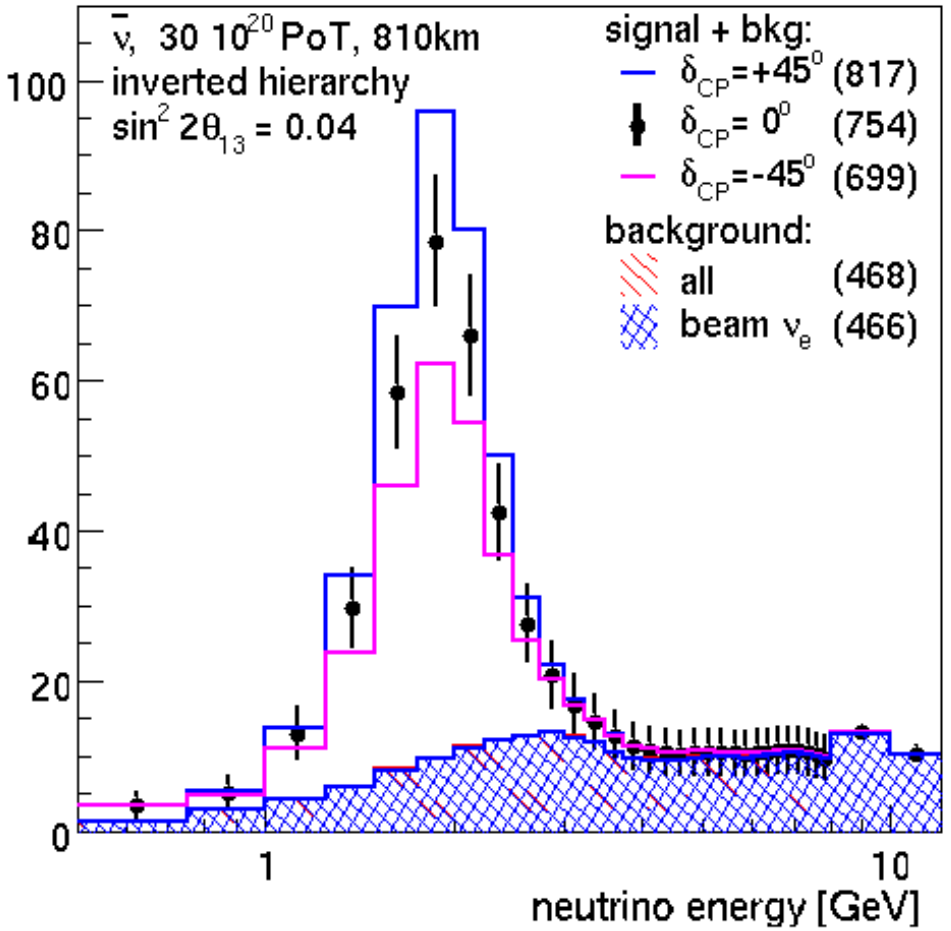


put S/B (<4GeV)

LAr spectra @ NOvA

- ✔ Anti-neutrino running and $\sin^2 2\theta_{13}=0.04$

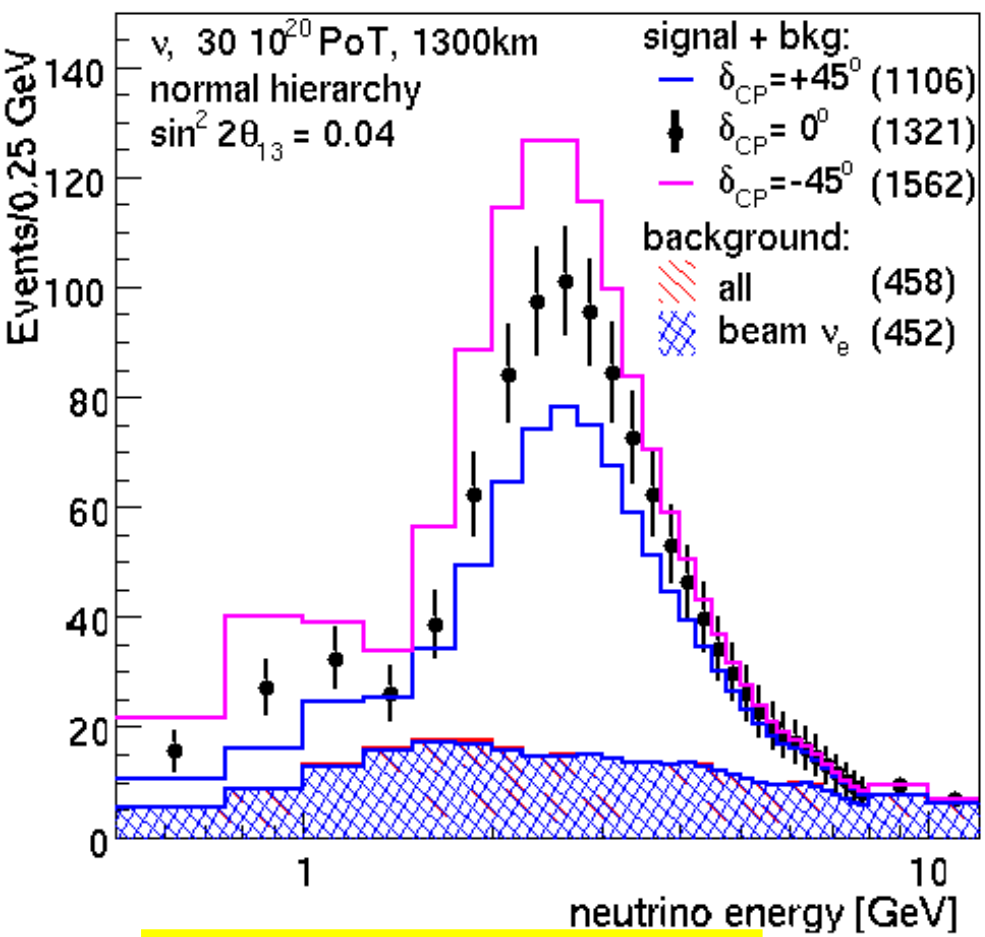


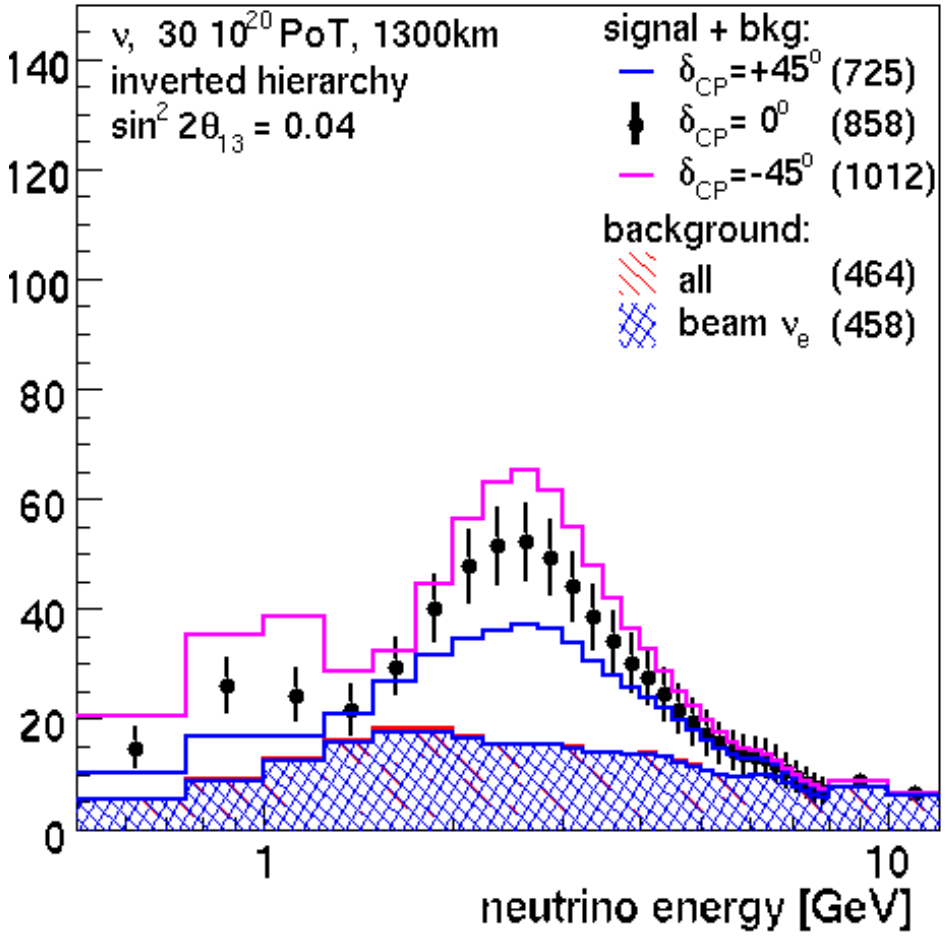


put S/B (<4GeV)

LAr spectra @ DUSEL

- ✔ Neutrino running and $\sin^2 2\theta_{13}=0.04$

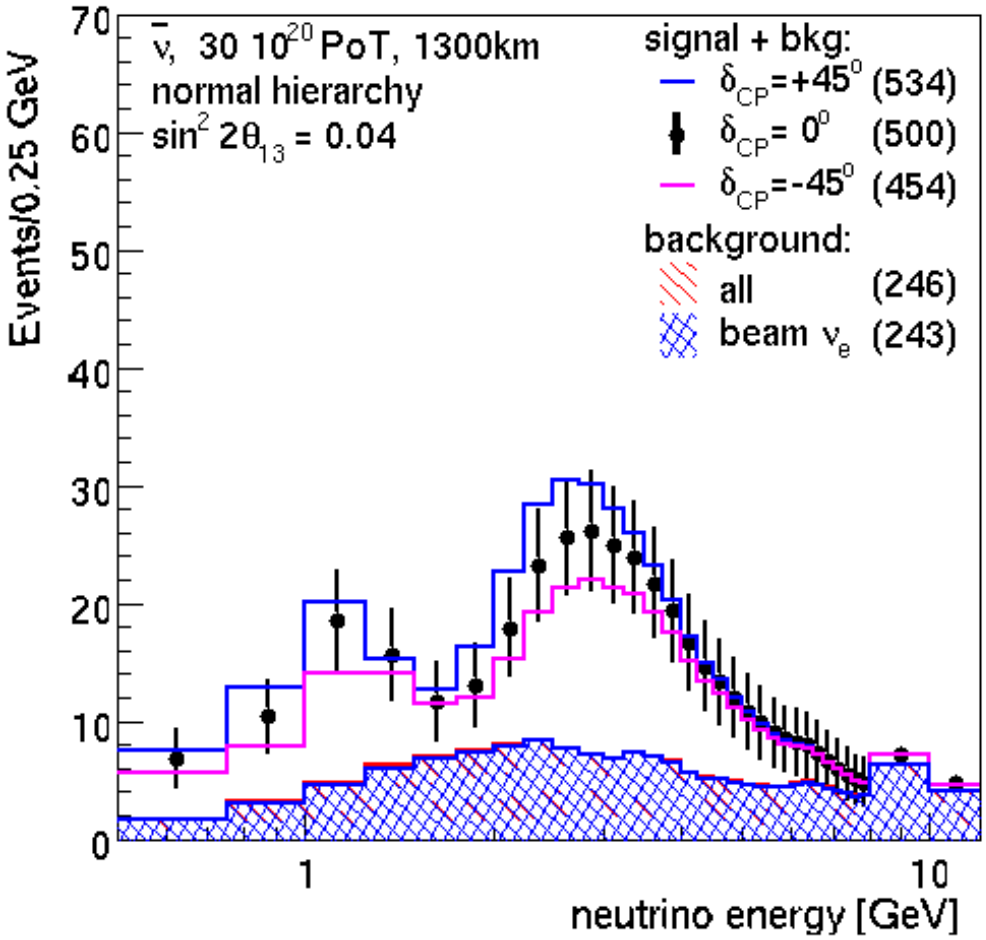


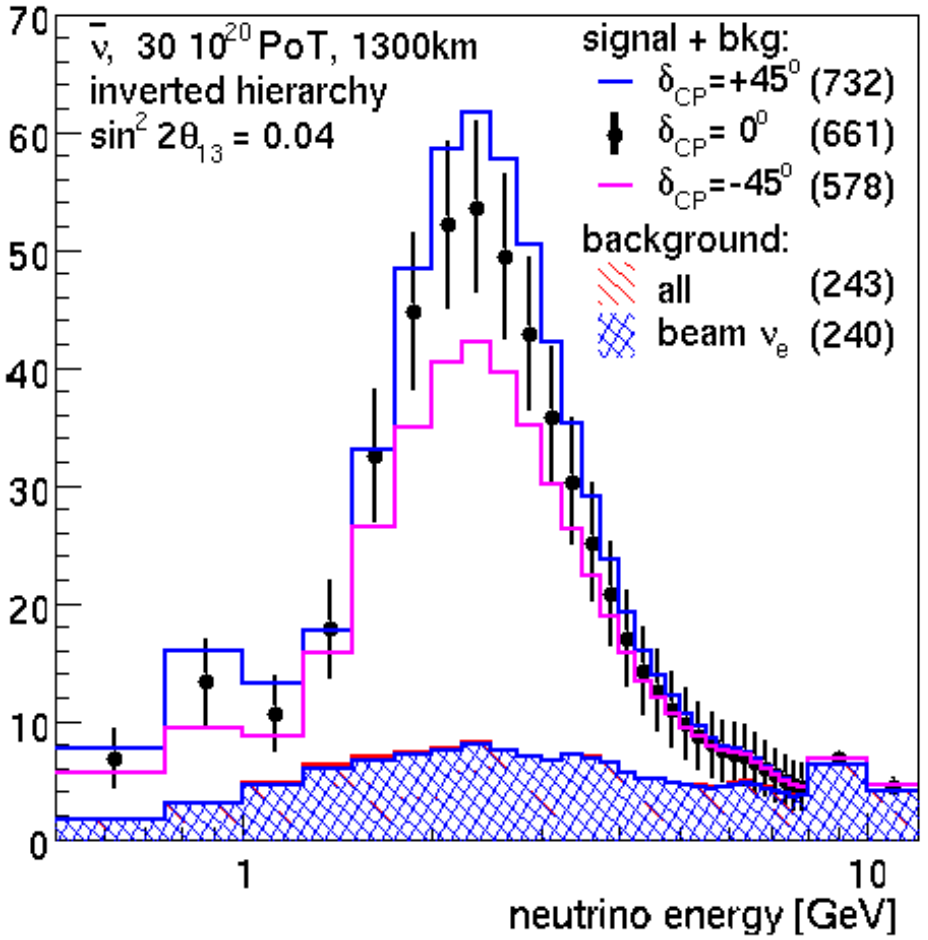


put S/B (<8GeV)

LAr spectra @ DUSEL

- ✔ Anti-neutrino running and $\sin^2 2\theta_{13}=0.04$





put S/B (<8GeV)

Water Cherenkov Detector

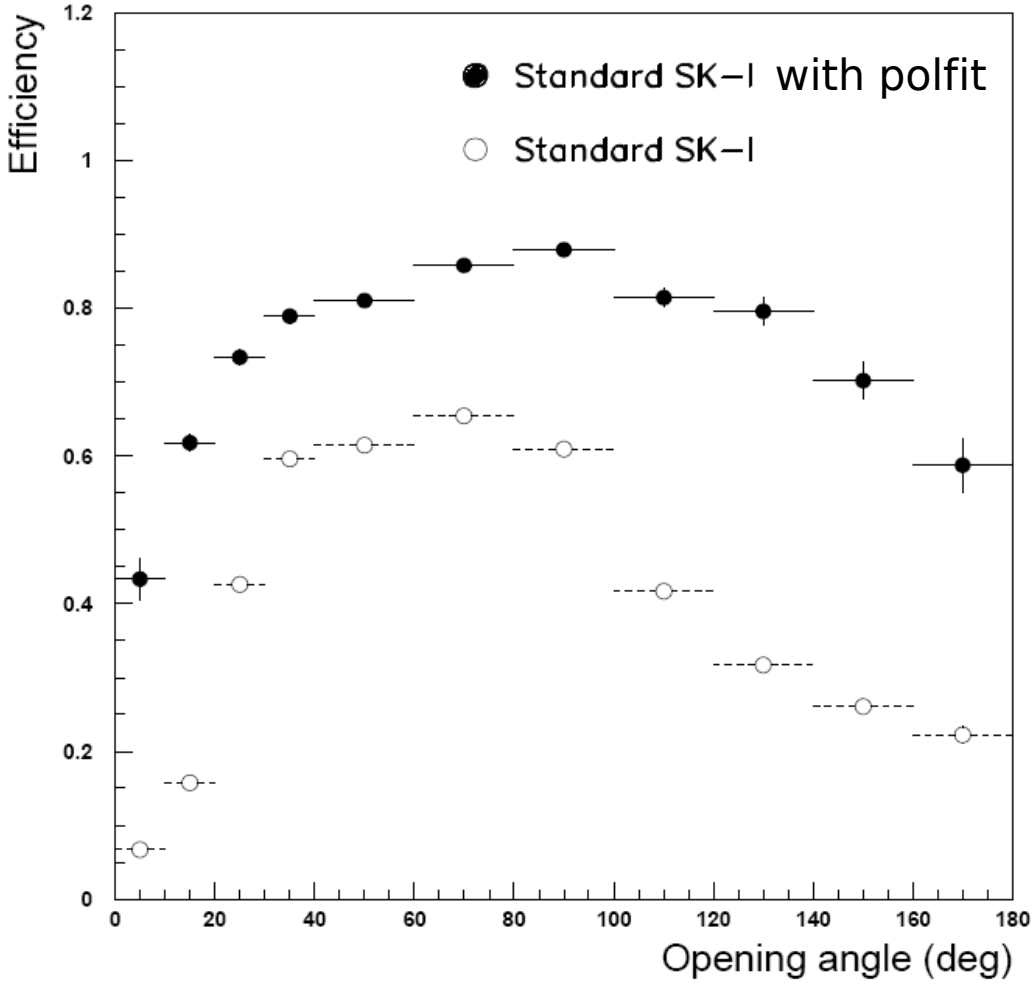
- ✔ 300 kton water Cherenkov (WCh) detector
- ✔ Must be underground to reduce cosmics rate
  -> DUSEL

- ✔ Two independent studies performed to improve selection of electron neutrino interactions
  C. Yanagisawa
  F. Dufour/E. Kearns

- ✔ Both use SuperK MC and follow similar strategy to improve separation between electrons and π^0 decays: very similar results are obtained

Water Cherenkov Detector

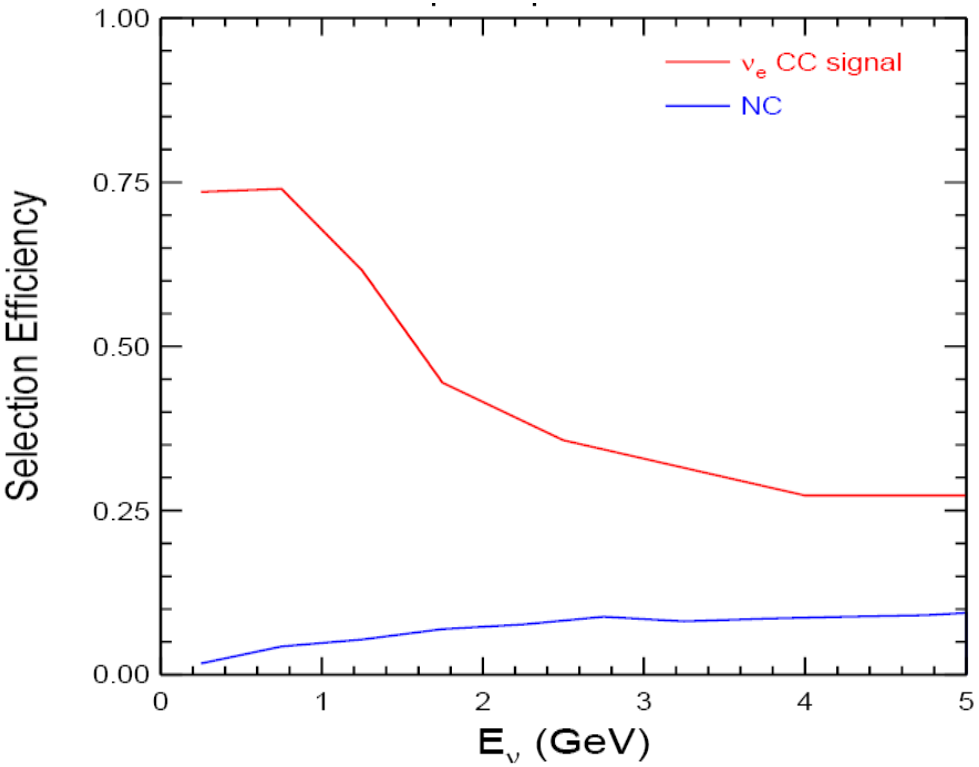
- Standard SuperK cuts are used to select single e-like events
- A π^0 reconstruction algorithm called Pattern-of-light fit (Polfit) is used to find second ring: improves π^0 eff. by 20-30%



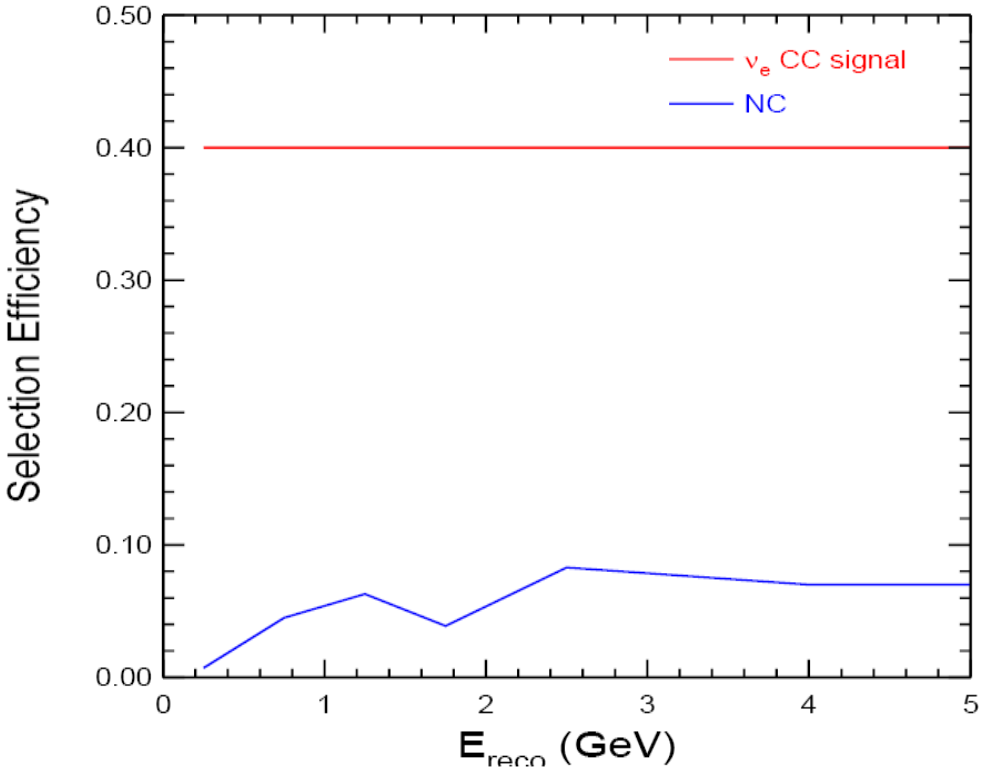
Water Cherenkov Detector

- The output of polfit and several other variables (some related to knowledge of beam direction) are used as input for a likelihood based analysis

SuperK pre-selection



Likelihood Analysis



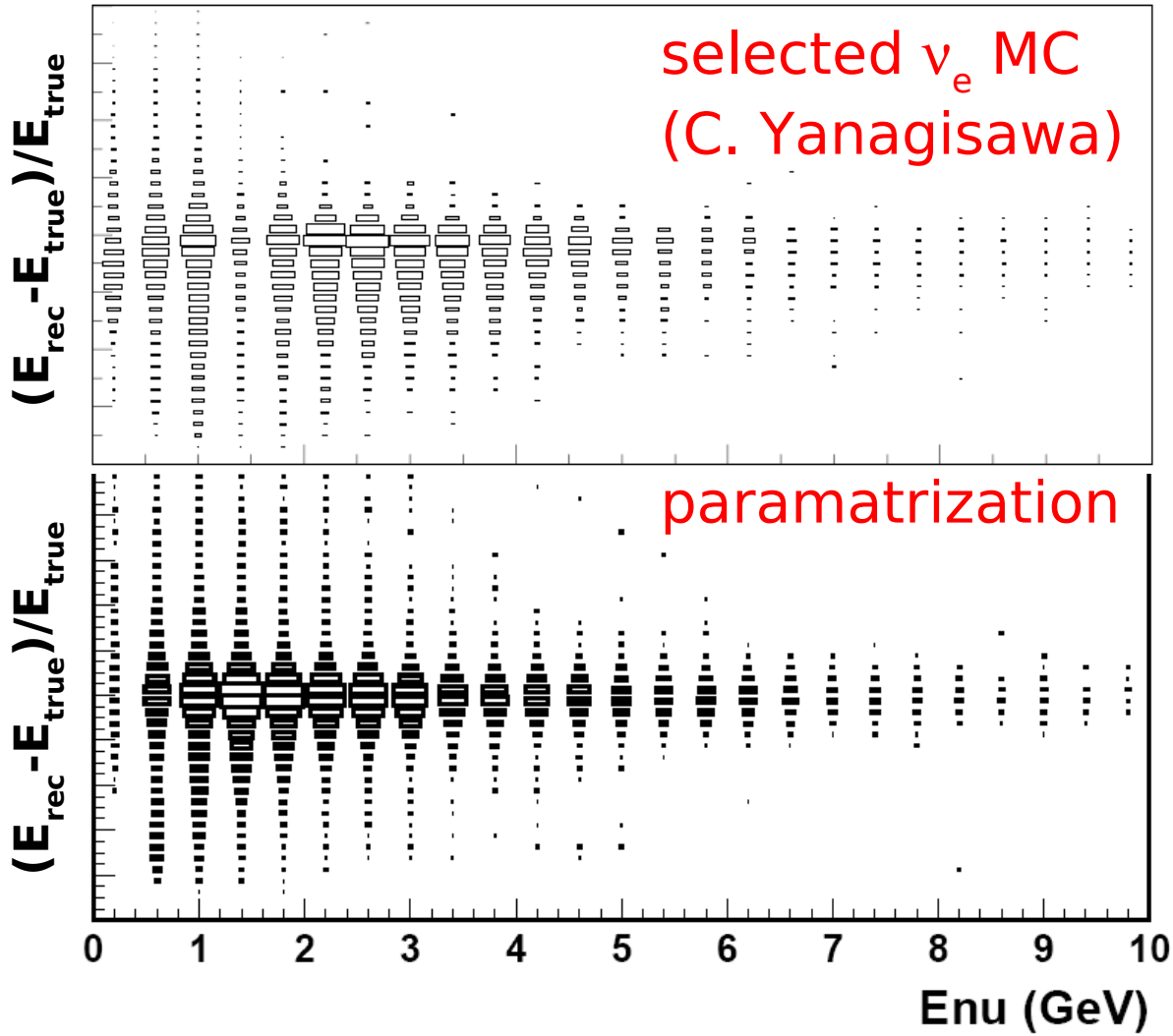
- Efficiencies are used for sensitivity calculations

Water Cherenkov Detector

- Parametrized smearing functions

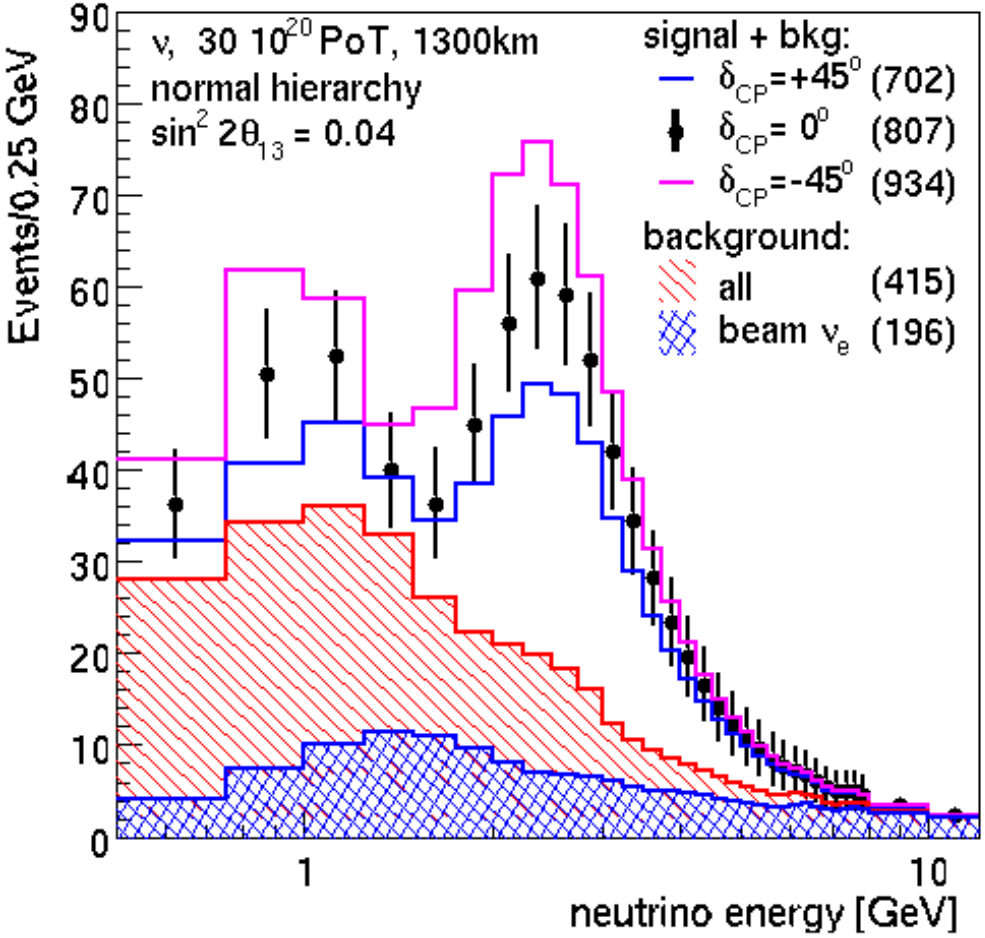
- ν_e CC: mostly QE
  $\sigma(E) \sim 10\%$
  at 1 GeV

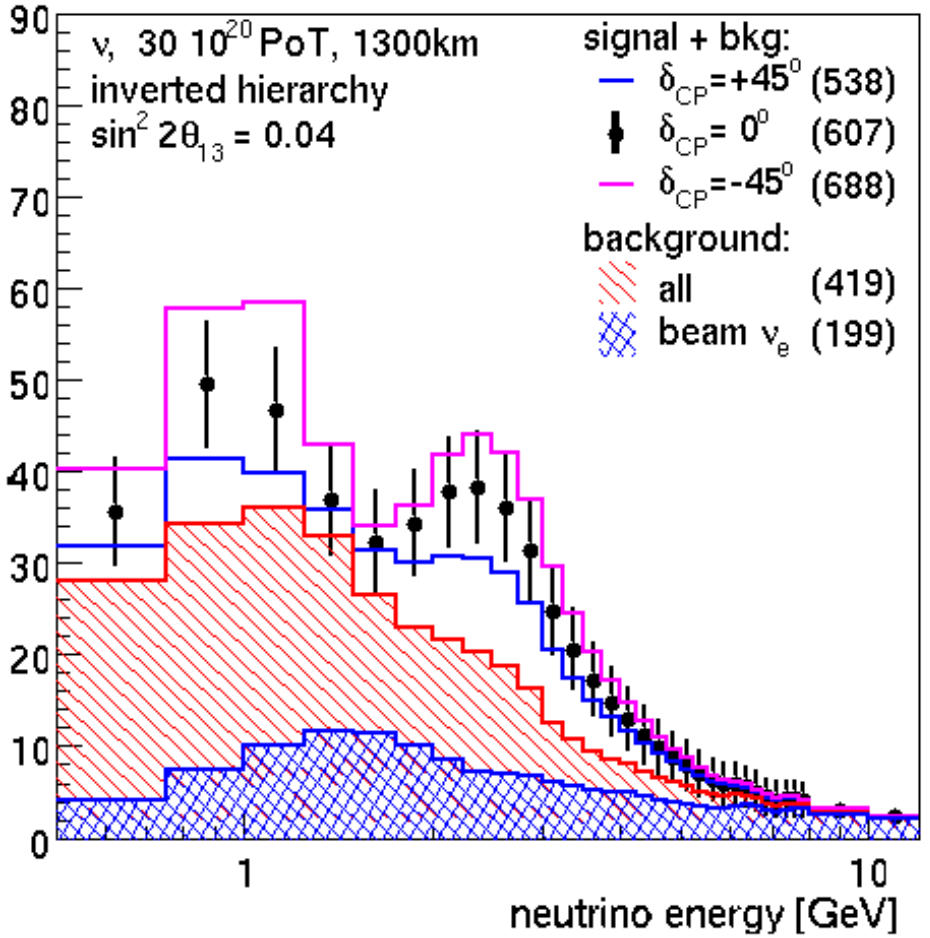
- ν_x NC: based on nuance



WCh spectra @ DUSEL

- ✔ Neutrino running and $\sin^2 2\theta_{13}=0.04$

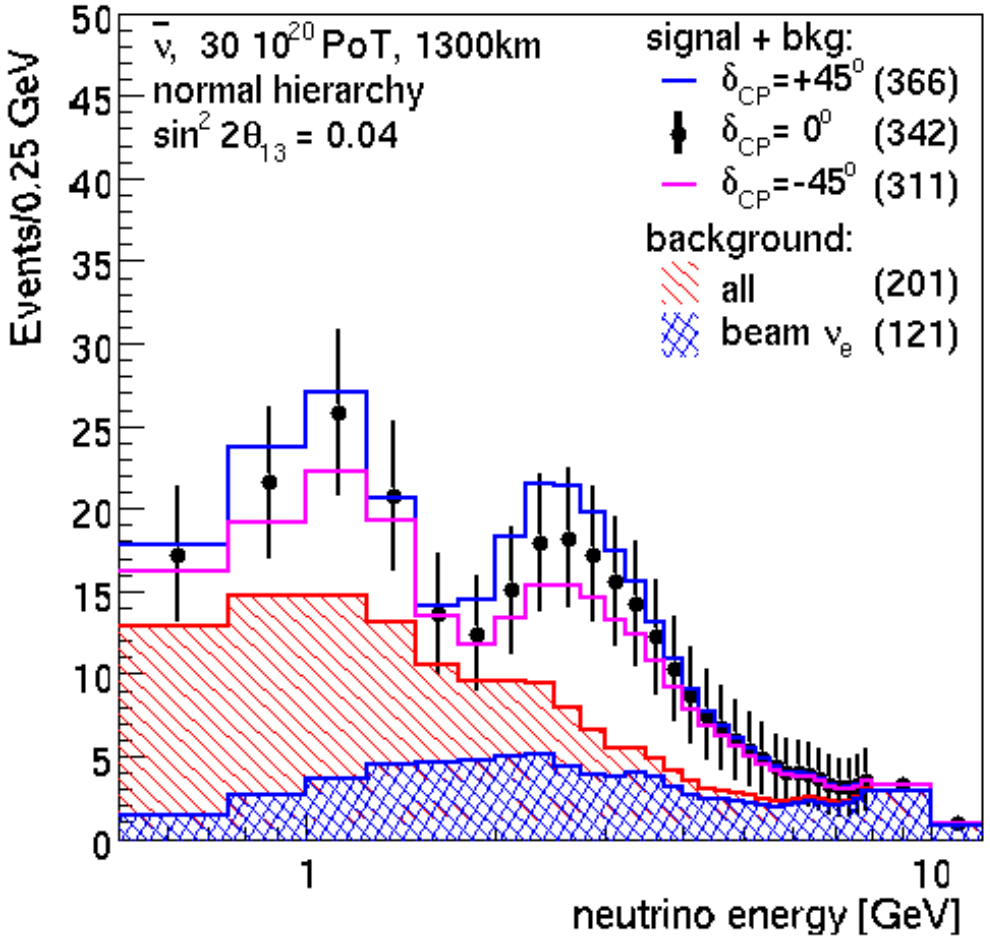


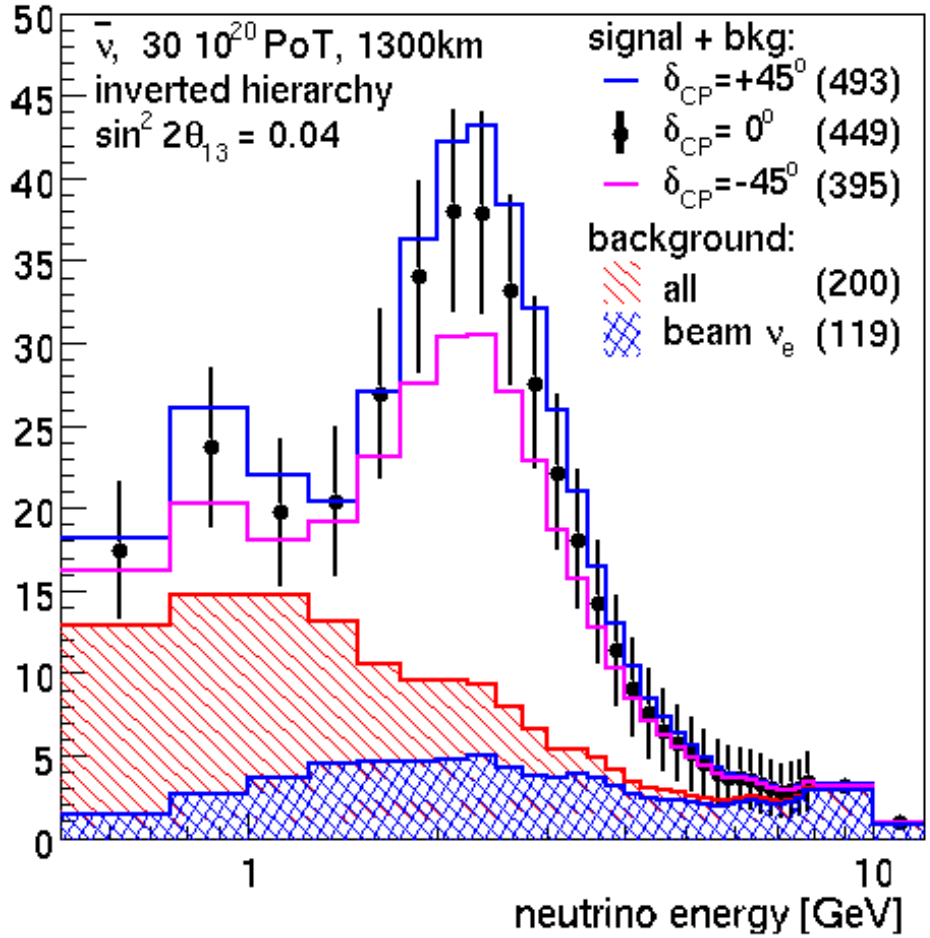


put S/B (<8GeV)

WCh spectra @ DUSEL

- ✔ Anti-neutrino running and $\sin^2 2\theta_{13}=0.04$





put S/B (<8GeV)

Sensitivity Studies

Sensitivity calculations

- Sensitivity to non-zero θ_{13}: fit spectrum generated for particular $(\theta_{13},\delta_{cp})$ to hypothesis with $\theta_{13}=0$
- Sensitivity to CP violation: fit spectrum generated for particular $(\theta_{13},\delta_{cp})$ to hypotheses $\delta_{cp}=0$ and π. Take worst χ^2. θ_{13} is allowed to float in fit
- Sensitivity to matter hierarchy: fit spectrum for particular $(\theta_{13},\delta_{cp})$ to hypothesis with opposite mass hierarchy. Both θ_{13} and δ_{cp} are allowed to float
- $(\theta_{13},\delta_{cp})$ measurement (for DUSEL only): parameter measurement for certain values

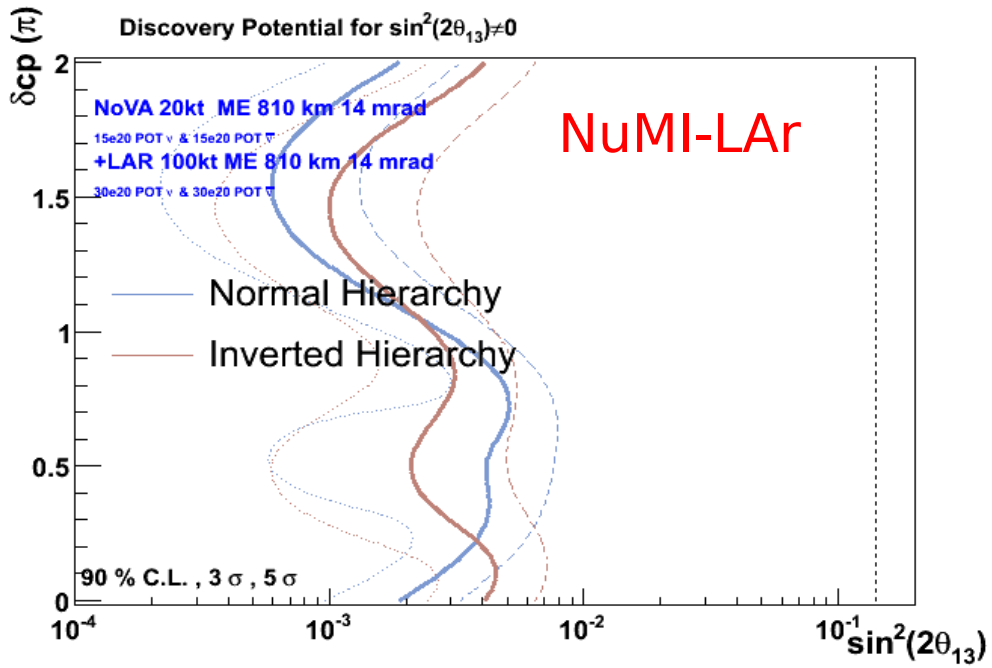
Input parameters & uncertainties

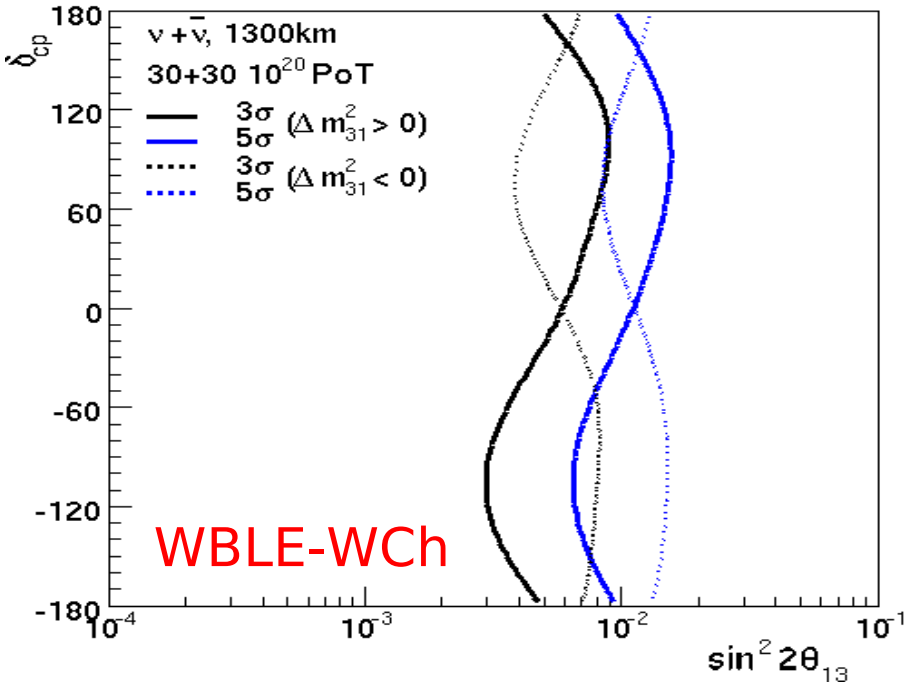
parameter	Uncertainty	
	NuMI off axis	FNAL-DUSEL
$\Delta m^2_{32} = 2.7\ 10^{-3}\ eV^2$	fixed	from $\nu_\mu \rightarrow \nu_\mu$
$\sin^2\theta_{23} = 1.0$	fixed	from $\nu_\mu \rightarrow \nu_\mu$
$\Delta m^2_{21} = 8.6\ 10^{-5}\ eV^2$	fixed	5%
$\sin^2 2\theta_{12} = 0.86$	fixed	5%
ρ = ???	fixed	5%
background	5%	10%
tools	custom program (N. Saoulidou)	GLoBES (M. Dierckxsens, M. Bishai, M. Diwan,...)

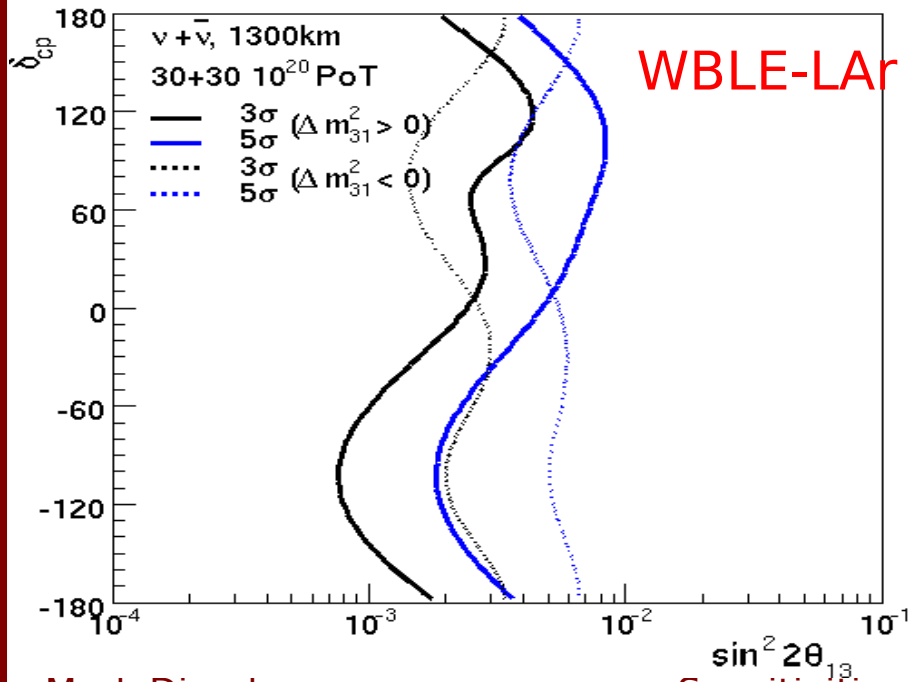
Sensitivity calculations

- Short names for various experiments:
  - NuMI-LAr: 100kt LAr det. in 0.8° off-axis NuMI beam at 810km
  - WBLE-WCh: 300kt Water Cherenkov det. in 120 GeV 0.5° off-axis wide band beam at 1300km
  - WBLE-LAr: same as above but 100kt LAr det.
- Limits quoted as the value of $\sin^2 2\theta_{13}$ above which the sensitivity is $\geq 3\sigma$ for 50% of δ_{CP} phases for the worst mass hierarchy case.
- Reminder: fits shown are for 30 10^{20} pot for neutrino and anti-neutrino running each

Sensitivity to $\sin^2 2\theta_{13} \neq 0$

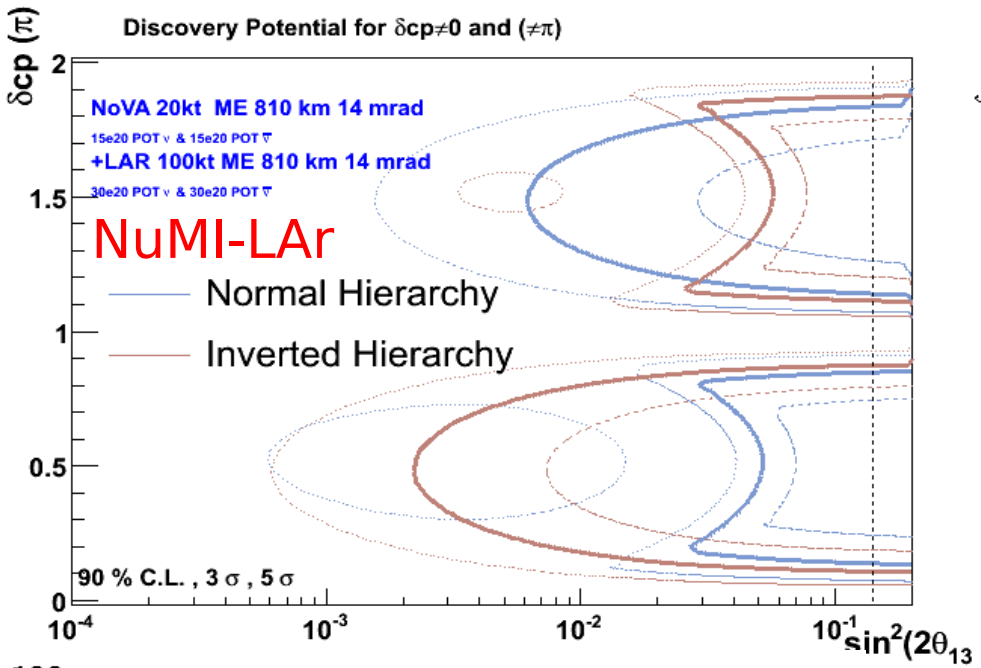


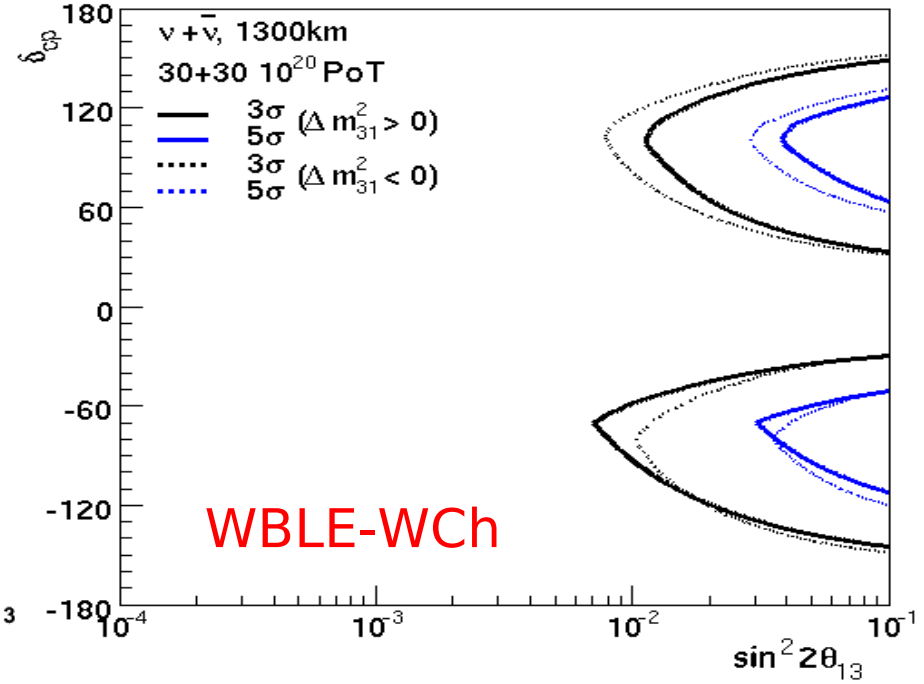


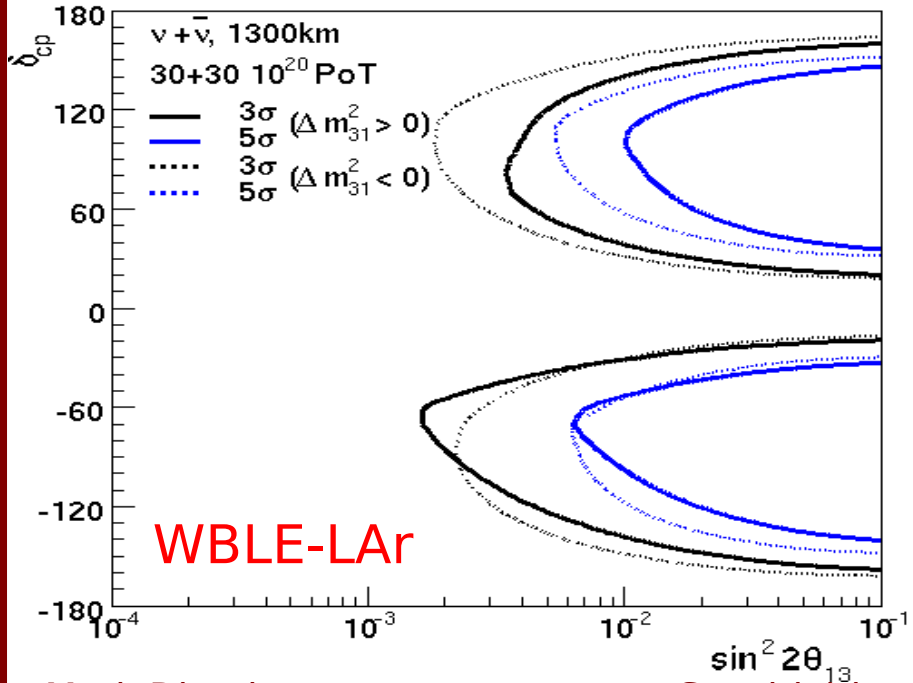


- ✔ NuMI-LAr: 0.002
- ✔ WBLE-LAr: 0.003
- ✔ WBLE-WCh: 0.006

Sensitivity to CP violation

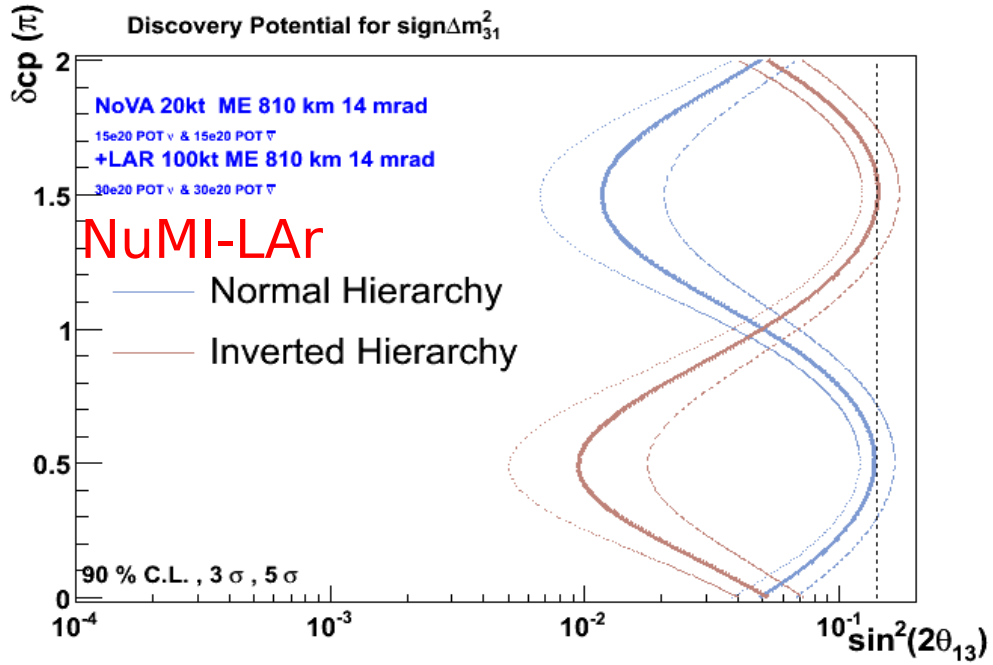


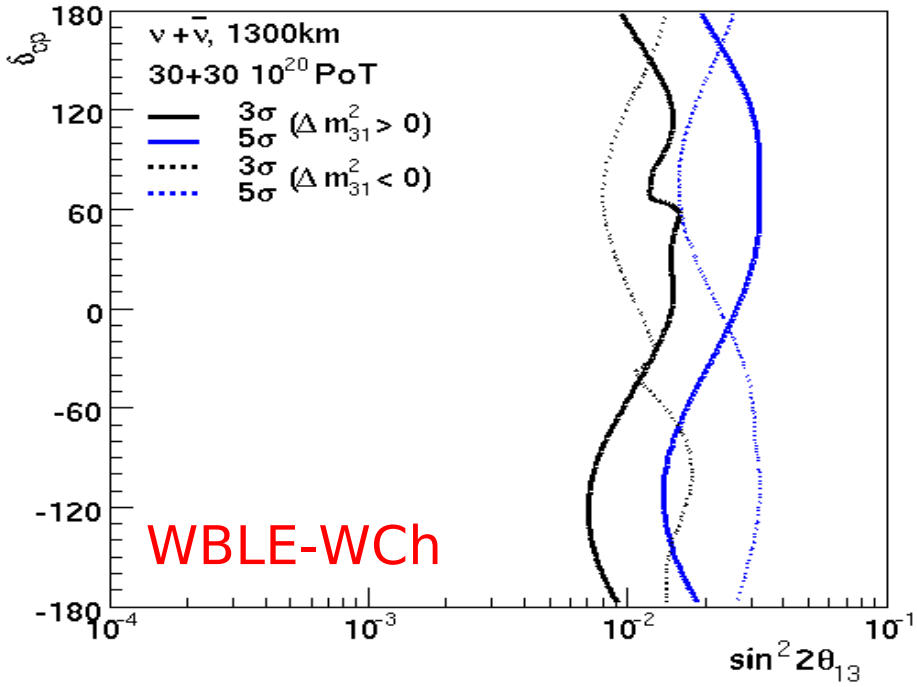


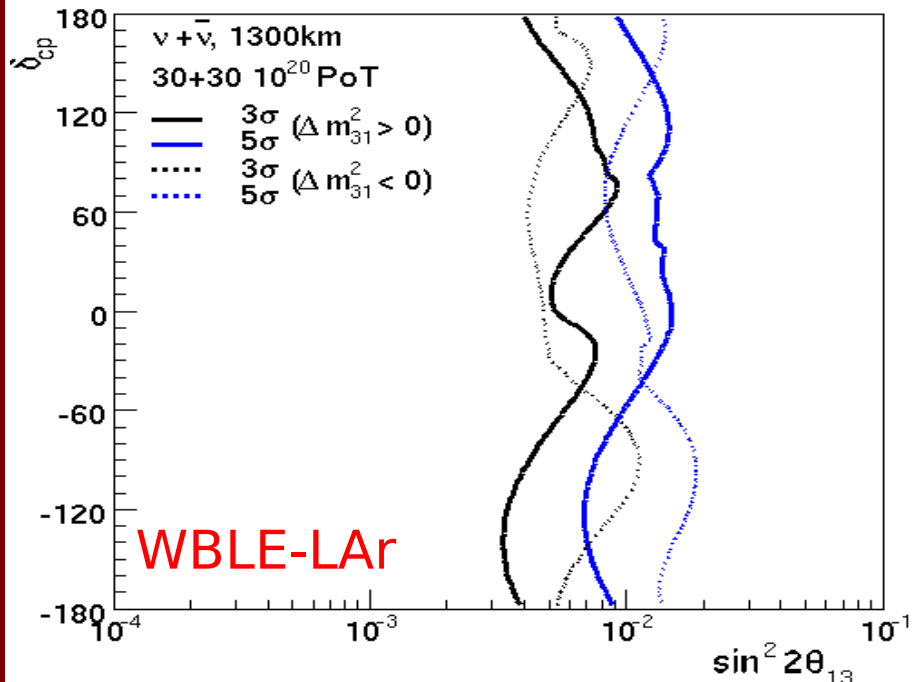


- ✔ NuMI-LAr: 0.03
- ✔ WBLE-LAr: 0.005
- ✔ WBLE-WCh: 0.03

Sensitivity to mass hierarchy



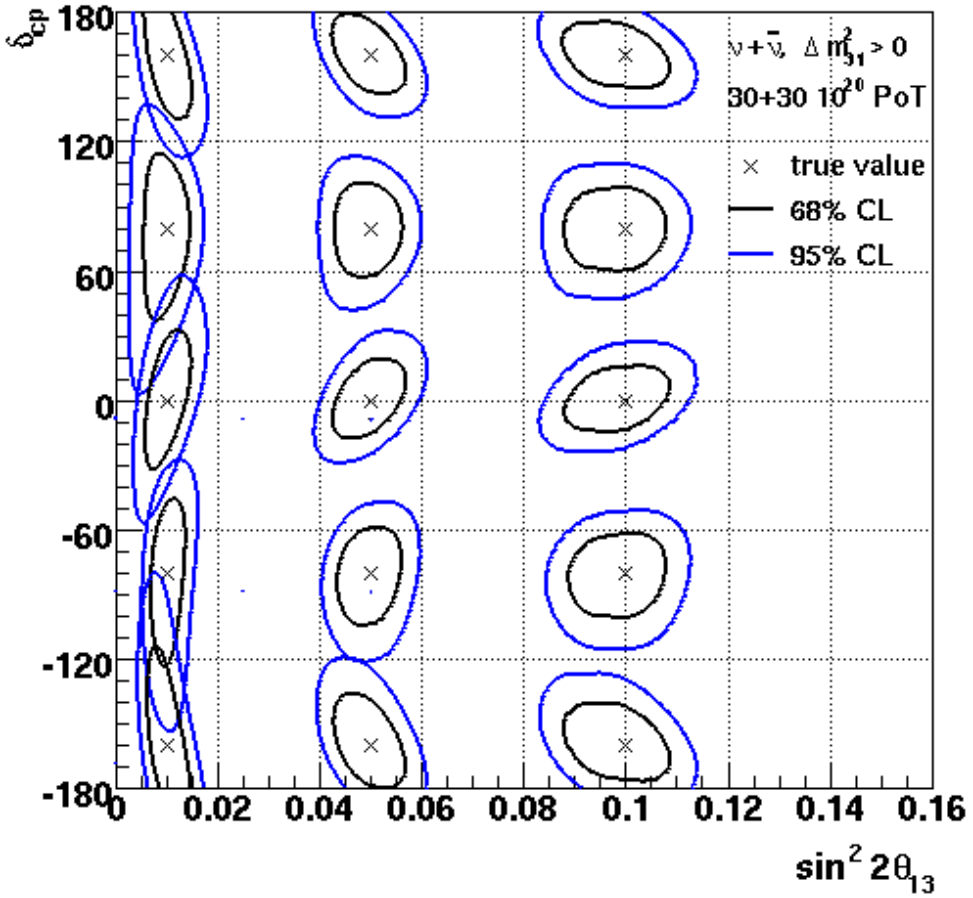




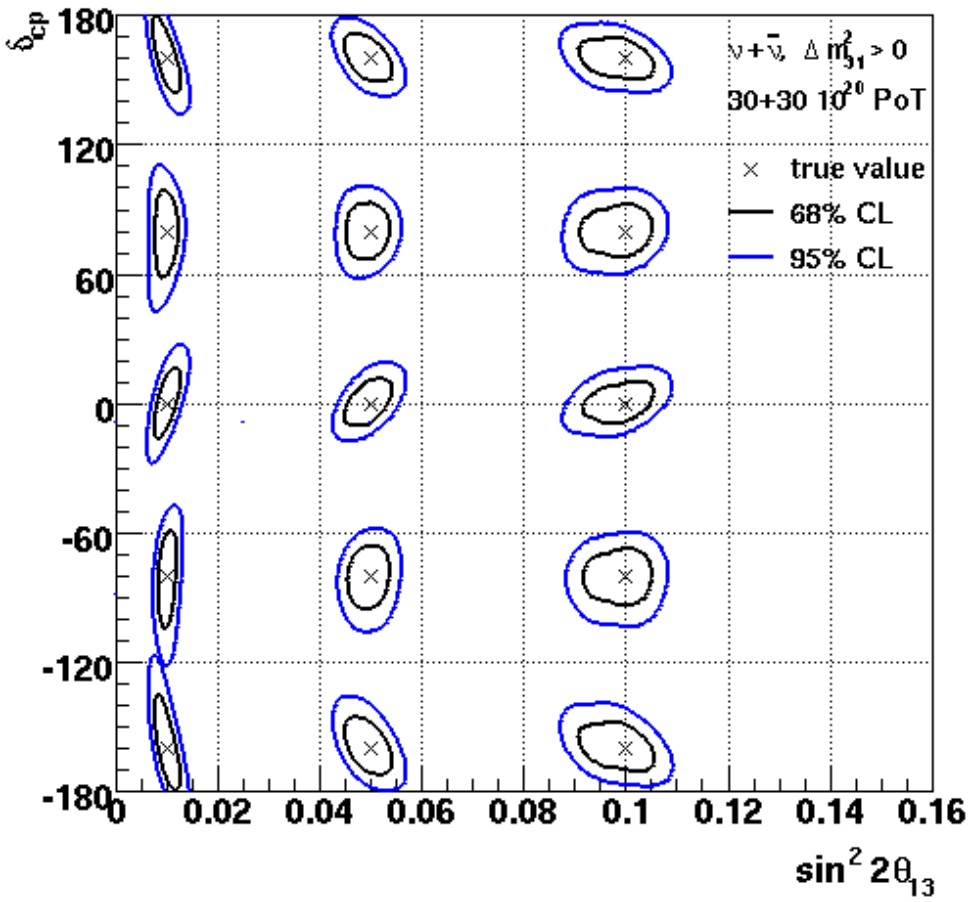
- ✔ NuMI-LAr: 0.05
- ✔ WBLE-LAr: 0.006
- ✔ WBLE-WCh: 0.01

(θ_{13},δ_{cp}) measurement

WBLE-WCh



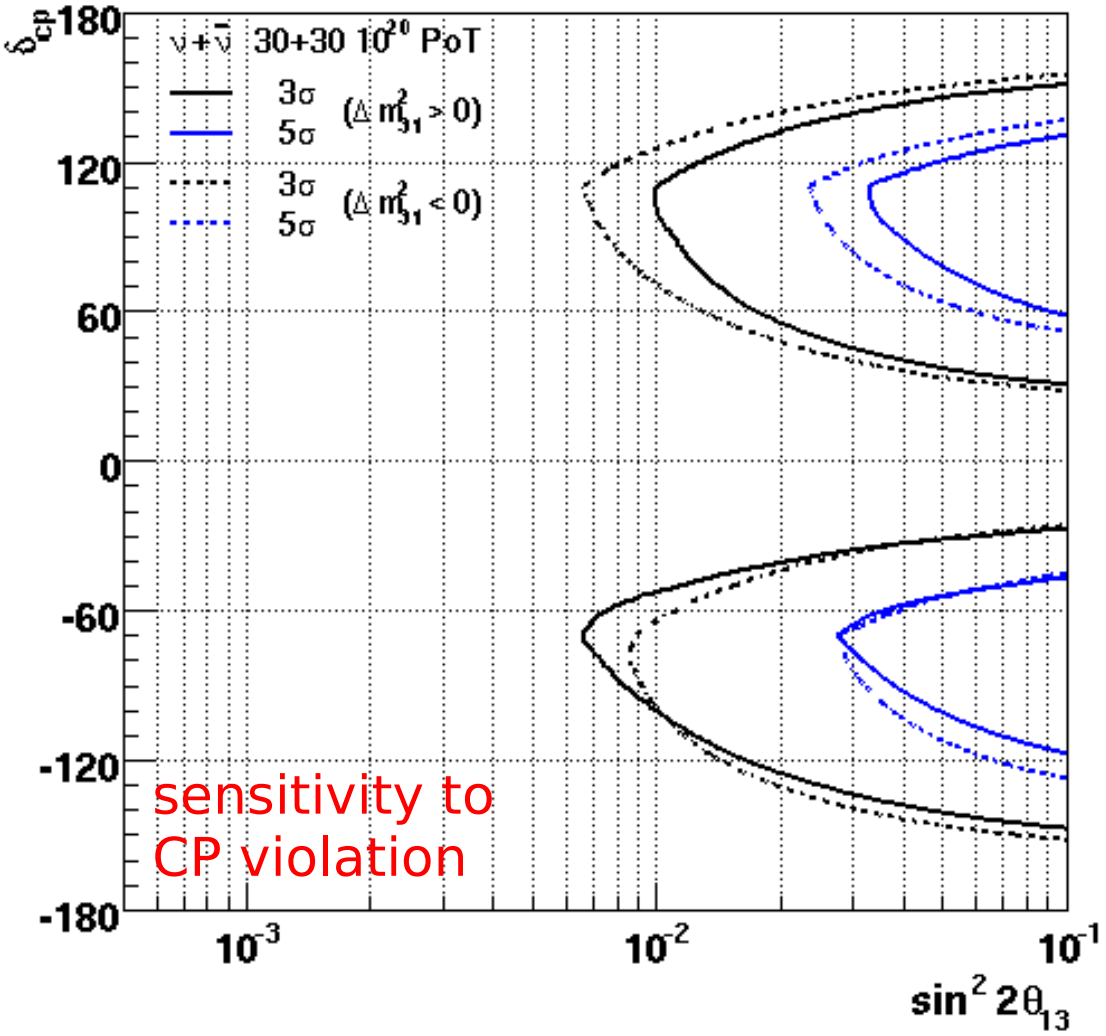
WBLE-LAr



- ✔ Measure $\sin^2 2\theta_{13}$ to 10% (6%) with WBLE-WCh (WBLE-LAr) for $\sin^2 2\theta_{13}>0.01$ independent of δ_{CP}

Background WBLE-WCh

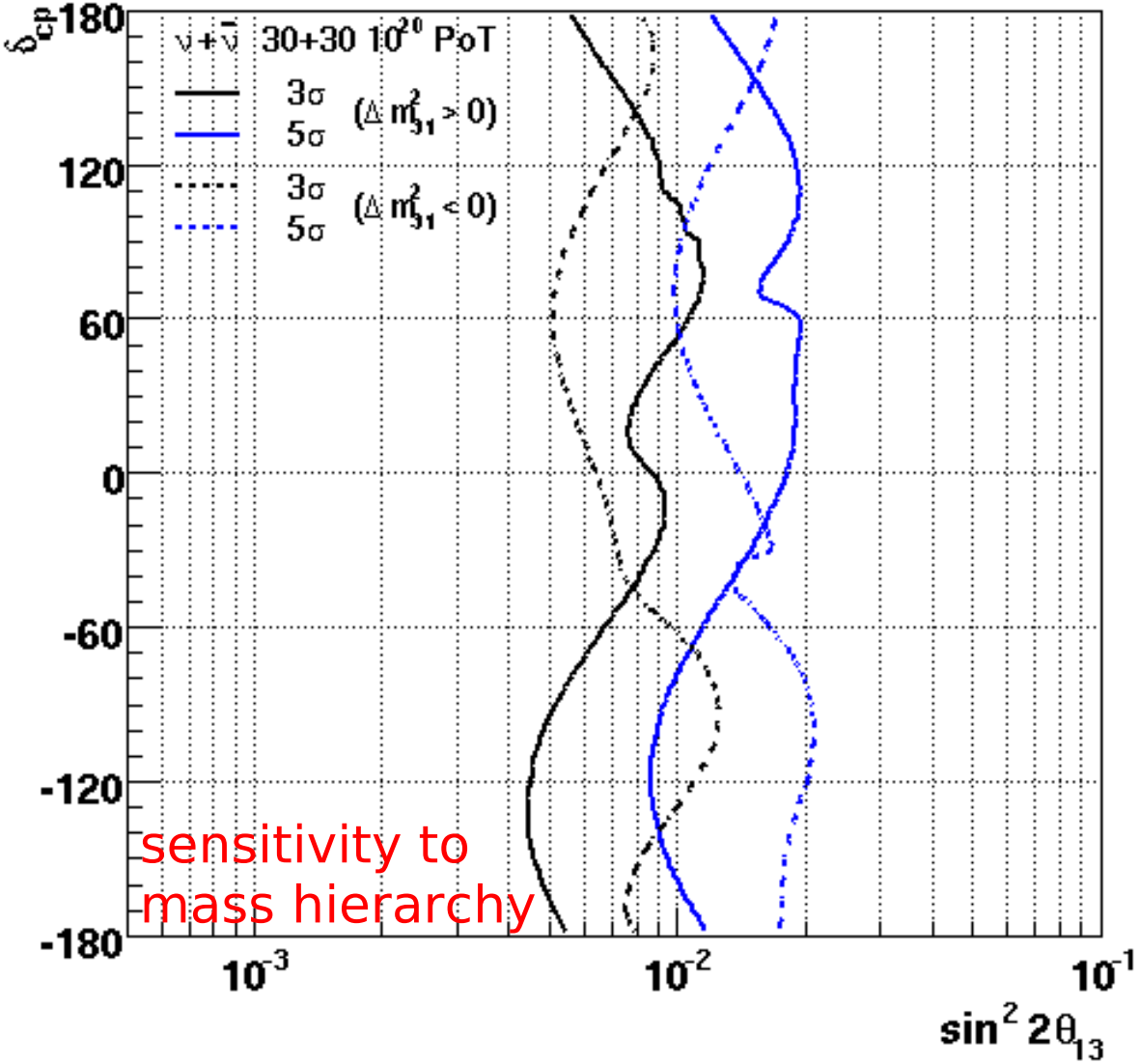
Reduce background uncertainty from 10% to 5%:



- $\sin^2 2\theta_{13}$:
  $0.006 \rightarrow 0.005$
- CP violation:
  $0.03 \rightarrow 0.02$
- $\text{sign}(\Delta m^2_{31})$:
  $0.01 \rightarrow 0.01$

Increased Statistics WBLE-WCh

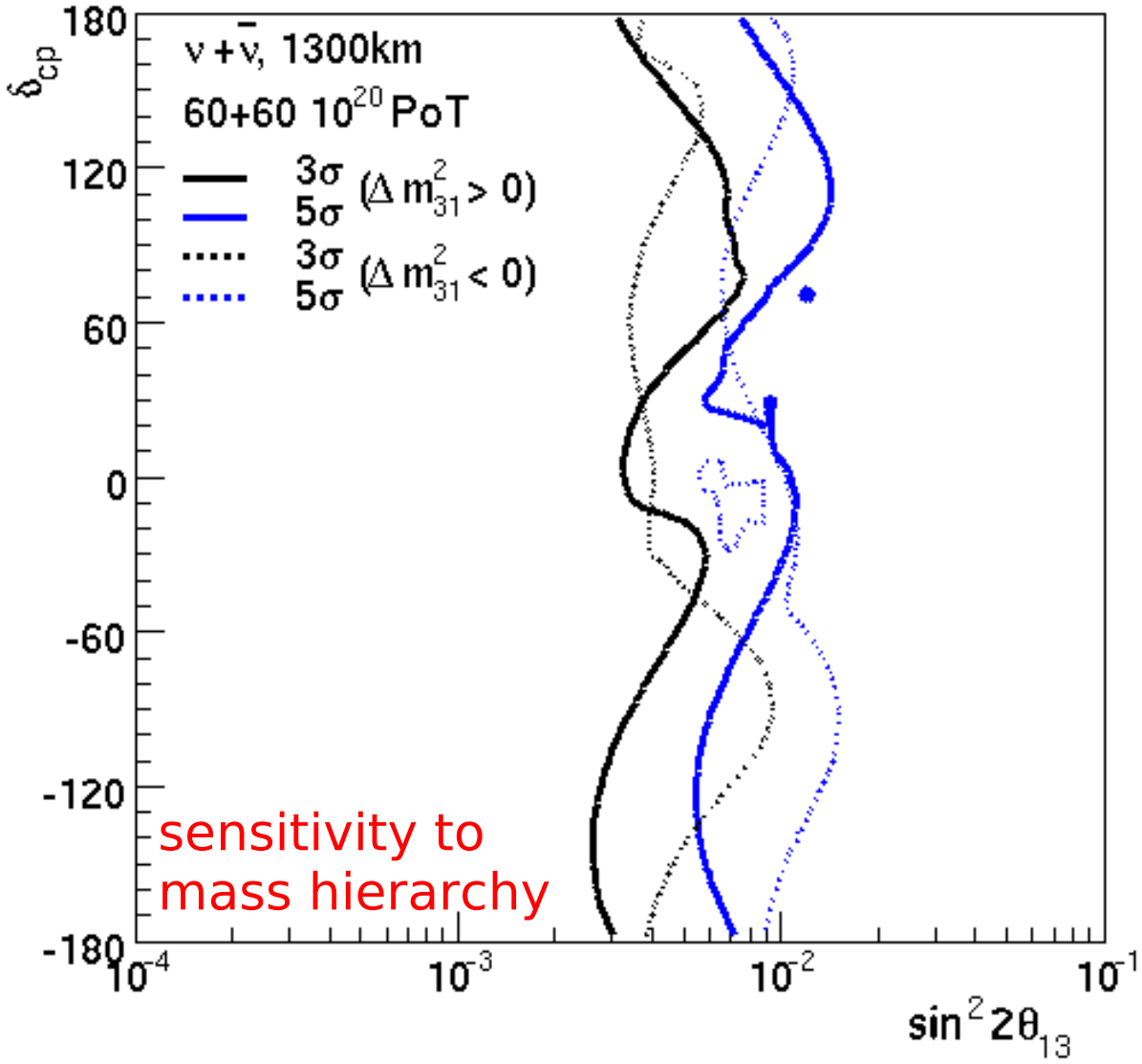
5% background uncertainty & 120 10^{20} pot for $\nu+\bar{\nu}$



- $\sin^2 2\theta_{13}$:
  $0.006 \rightarrow 0.004$
- CP violation:
  $0.03 \rightarrow 0.01$
- sign(Δm^2_{31}):
  $0.01 \rightarrow 0.008$

Increased statistics WBLE-LAr

60 10^{20} pot for ν and $\bar{\nu}$ each



$\sin^2 2\theta_{13}$:

$0.003 \rightarrow 0.002$

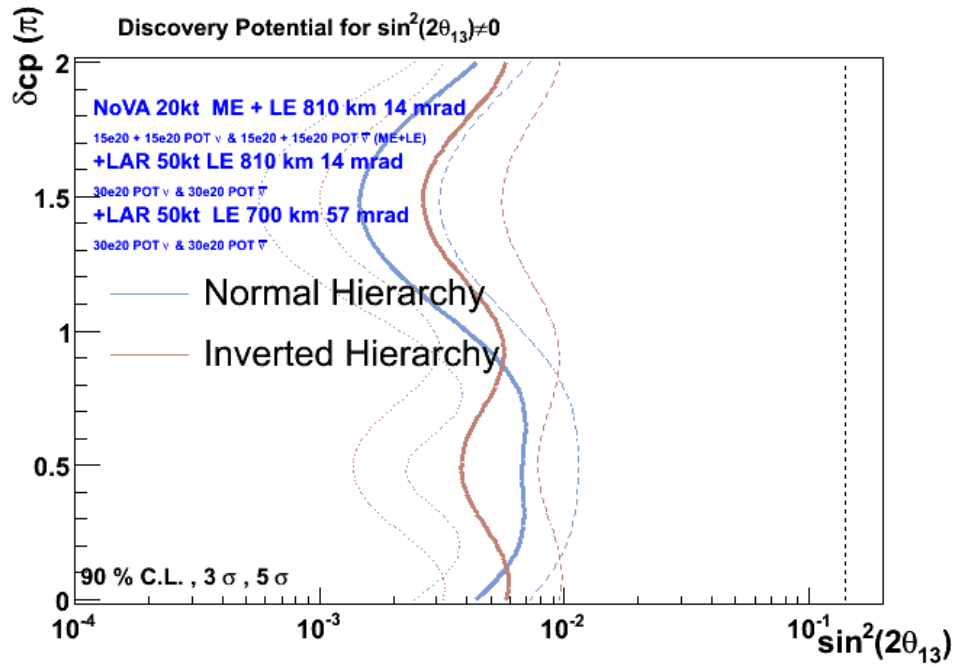
CP violation

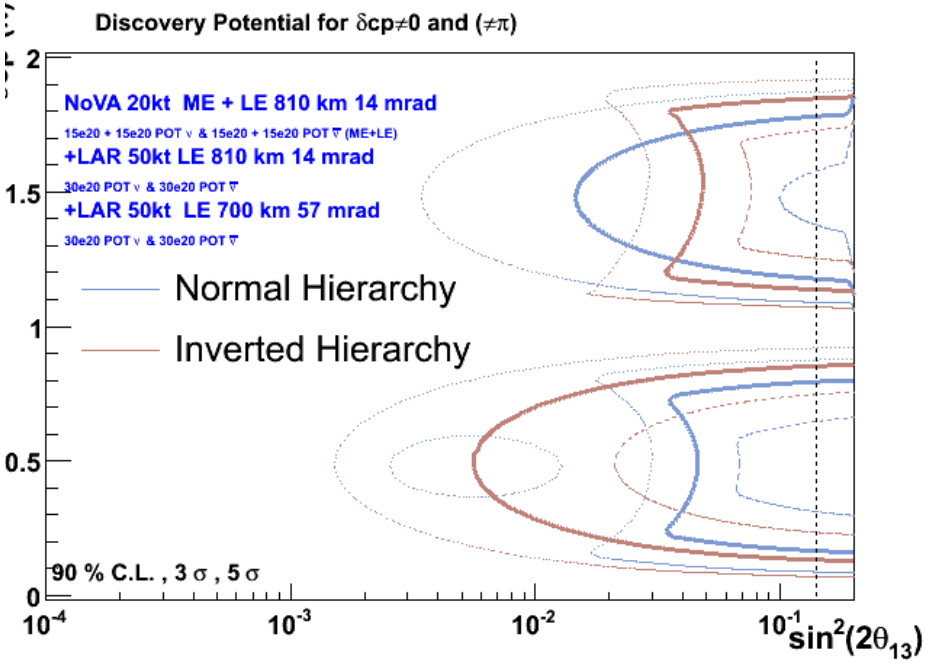
$0.005 \rightarrow 0.003$

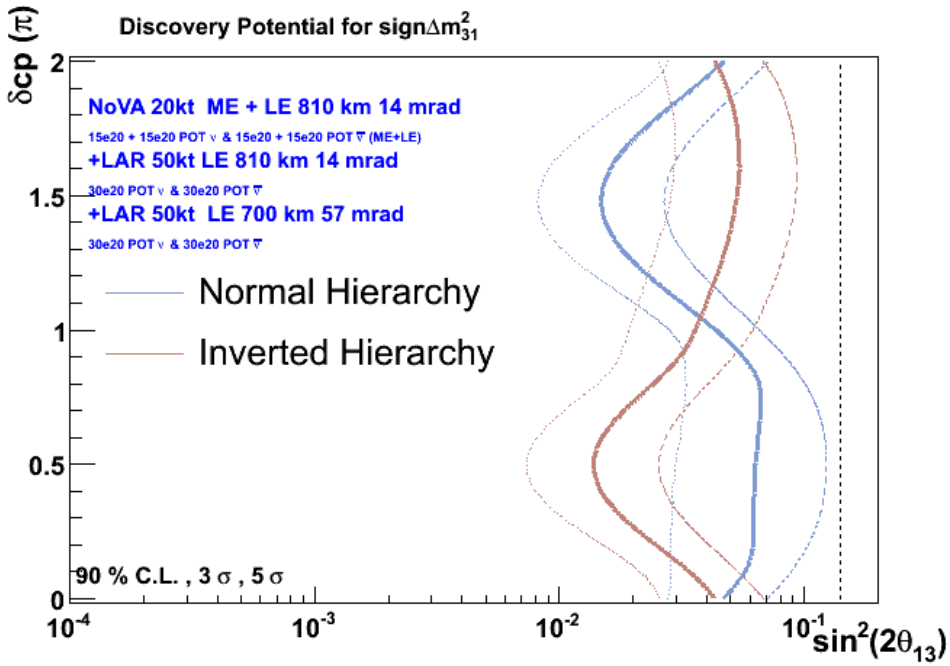
sign(Δm^2_{31}):

$0.006 \rightarrow 0.004$

2nd off-axis detector







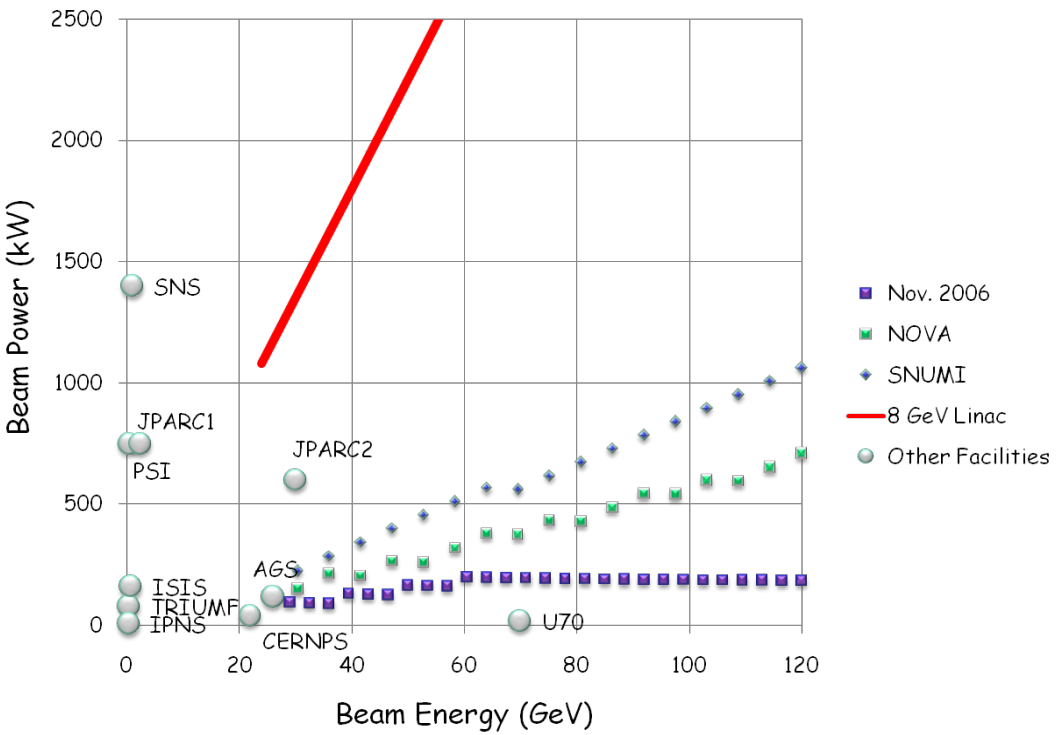
50kt LAr 0.8° &
50kt LAr 3° off axis:

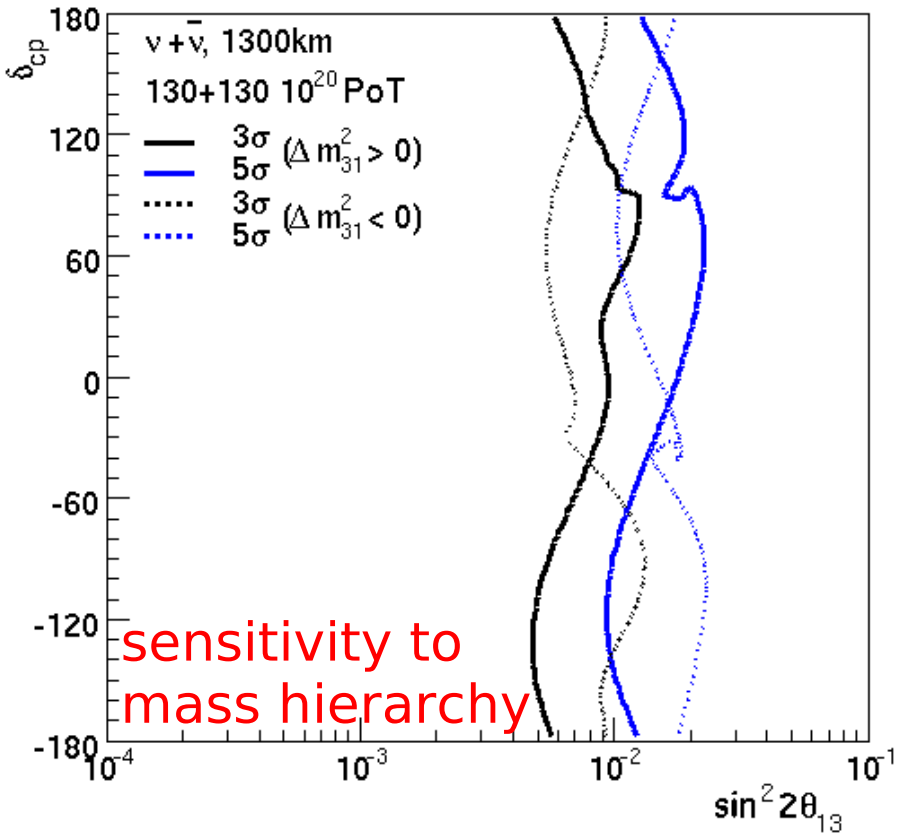
- ✔ $\sin^2 2\theta_{13}$: 0.005
- ✔ ~~CP~~: 0.04
- ✔ sign(Δm^2_{31}): 0.04

Project X

- From Y.K. Kim's talk at HEPAP meeting July 07: 2.6MW at 60GeV

  http://www.science.doe.gov/hep/HEPAPJuly2007Agenda.htm





- $\sin^2 2\theta_{13}$: 0.003
- ~~CP~~: 0.01
- sign(Δm^2_{31}): 0.007

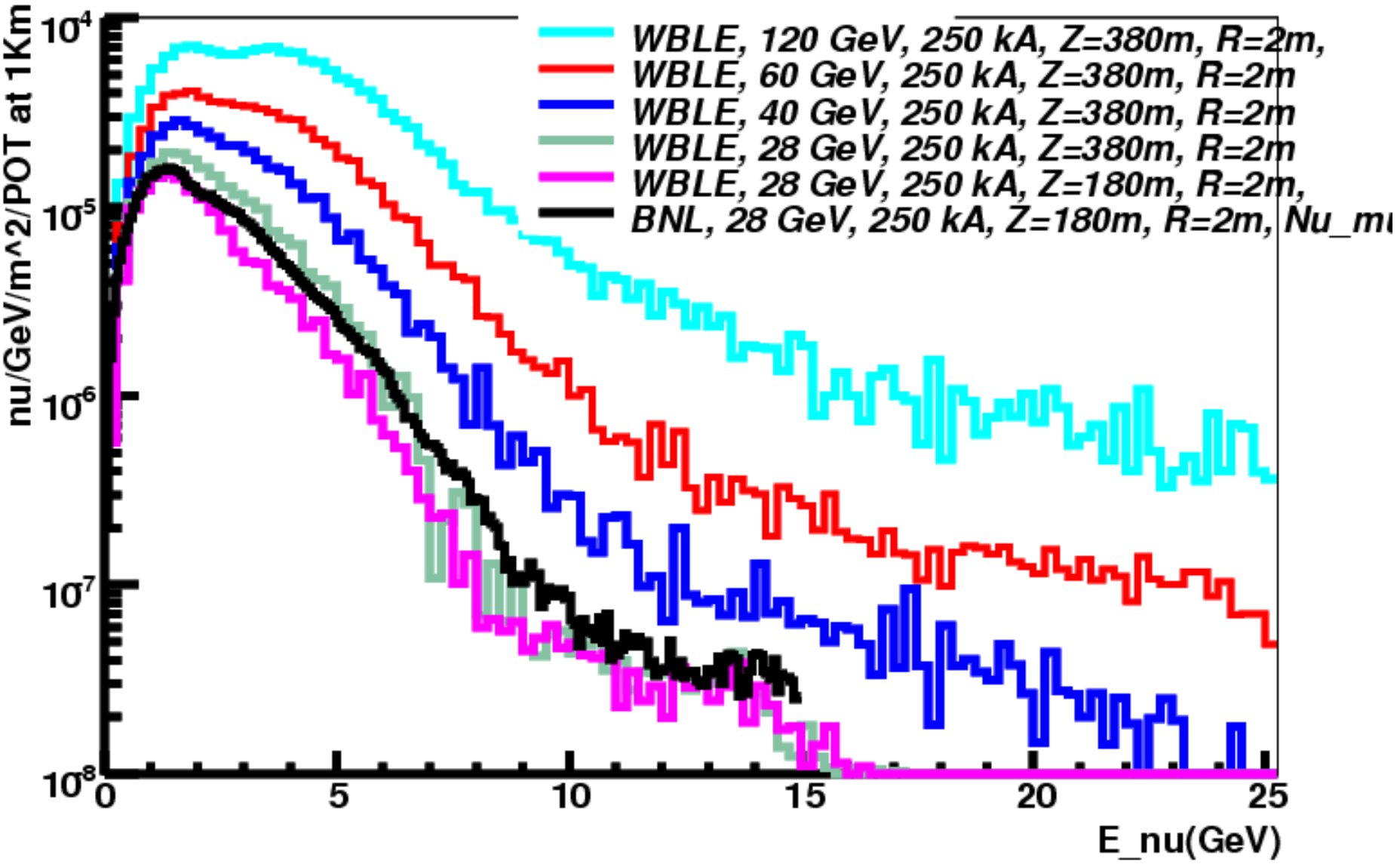
Conclusions

still to write...

- More information and supporting documents available at :
  http://nwg.phy.bnl.gov/~diwan/nwg/fnal-bnl/

Backup Slides

Wide band beam



WCh detector

- ✔ put some plots from Chiaki/Fanny

Background WBLW-WCh

- ✔ put plots with x2 background reduction

Other Off-axis combinations